Pediatr Radiol (2006) 36: 485–490
DOI 10.1007/s00247-005-0091-0

ORIGINAL ARTICLE

Gabriel Chodick · Cécile Ronckers · Elaine Ron · Varda Shalev

The utilization of pediatric computed tomography in a large Israeli Health Maintenance Organization

Received: 31 August 2005 / Revised: 1 December 2005 / Accepted: 4 December 2005 / Published online: 22 March 2006

Abstract *Background*: Concern has been raised about the potential risks related to radiation exposure from CT scans, particularly among children. However, to date, there are few data available describing the magnitude of pediatric CT utilization. *Objective*: The aim of the study was to explore patterns of CT use in pediatric patients, with respect to time, use of multiple scans, body regions imaged, and medical diagnoses. *Materials and methods*: Records of 22,223 scans performed on 18,075 people aged ≤18 years over the period 1999–2003, including diagnoses recorded within 21 days after the examination, were obtained from a large Israeli Health Maintenance Organization (1,600,000 members). *Results*: The highest annual CT examination rate (per 1,000) was recorded in 2001 (10.1) compared to 7.0 and 6.3 in 1999 and 2003, respectively. The lowest rate (three scans per 1,000) was found for 3-year-old children, with increasing rates with age. The head was the most frequently scanned region, both in young children (78%) and adolescents (39%). Symptoms of ill-defined conditions and injuries were documented in 22% and 10% of all scans, respectively. *Conclusions*: Although the results suggest that children comprise only 3% of all patients undergoing CT, this important modality must be carefully used because of their increased radiosensitivity, higher effective radiation doses, and longer life expectancy.

G. Chodick · V. Shalev
Maccabi Healthcare Services,
27 Ha'Mered Street,
Tel Aviv 68125, Israel

G. Chodick (✉) · C. Ronckers · E. Ron
Radiation Epidemiology Branch, National Cancer Institute,
6120 Executive Blvd., MSC 7238, Executive Plaza South,
Room 7049,
Bethesda, MD 20892-7238, USA
e-mail: Chodickg@mail.nih.gov
Tel.: +1-301-5943262
Fax: +1-301-4020207

Keywords CT · Radiation · Israel · Children

Introduction

Due to its extraordinary value in diagnosis and follow-up, the use of CT scanning has increased rapidly since its introduction in 1972. Whereas, CT scans were estimated in 1989 to account for about 2% of all X-ray examinations in the United Kingdom and about 20% of the resultant collective dose, more recent data indicate that the contribution to collective dose had risen to 40% in 1997/8 [1] and 47% in 2001/2 [2].

While CT scans are invaluable to the practice of modern medicine, concern about the potential cancer risks related to radiation exposure has been raised; particular concern relates to the excessive radiation exposure due to imprecise use of CT machines and performance of non-essential CT scans [3–6]. This is of special interest in young patients who not only have a longer life expectancy and thus more potential years at risk, but who also have a higher radiosensitivity than adults [7].

The Israel Ministry of Health regulates the number of CT scanners purchased in the country and current regulations allow only one scanner per 150,000 inhabitants. Thus, Israel has a relatively small number of CT scanners per capita (7.5 per million inhabitants) compared to an average of 17.4 per million in countries with a similar health-care level [8]. Nonetheless, the overall CT examination rate (78.0 per 1,000) in Israel is markedly higher than in most other countries of the same health-care level (Fig. 1). This high CT examination rate suggests that CT use patterns should be studied. To date, however, no valid data concerning CT use among pediatric patients in Israel have been published.

The aims of the current study were to explore patterns of CT use in children and adolescents over time, to describe the age and sex distribution of examined patients, to determine the percentage of patients undergoing multiple CT scans, and to examine what parts of the body are imaged, as well as what diagnoses are associated with

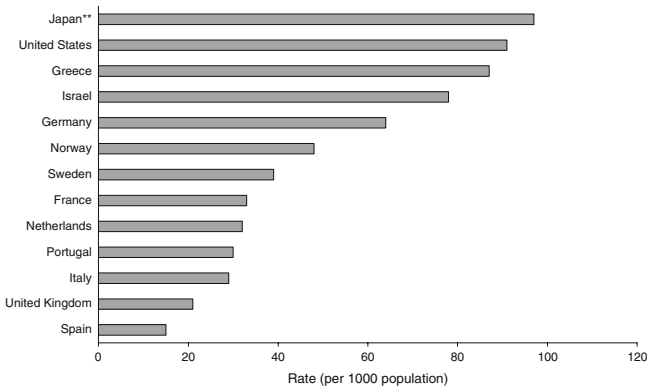


Fig. 1 Annual rates of CT procedures per 1,000 population (1991–1996) in Israel, Japan, US, and selected European countries (Japanese data from reference 26; other data from reference 8)

referral for scans. The results were compared with those in other similar populations.

Materials and methods

The study was conducted in Maccabi Healthcare Services (MHS), Israel's second largest Health Maintenance Organization (HMO). Established in 1941, MHS currently has a national membership of 1.6 million people (24% of the Israeli population), including 560,000 persons aged 18 years or less, living throughout the country. The core of MHS activity is conducted by its 2,700 independent or salaried physicians, 250 diagnostic institutes, and 50 independent imaging centers (of which 34 are at general hospitals and tertiary medical centers serving the national Israeli population) that provide services on a contract basis. The 1994 Israeli National Health Act (NHAI) requires MHS to pay for all members' necessary CT examinations, and thus these examinations are well documented in the MHS billing system. Since data pertaining to services provided prior to 1999 have not been fully stored in the MHS computerized database, we restricted the study to the period 1999–2003.

From the MHS computerized database, we obtained all billing records of CT examinations performed on members aged ≤18 years between January 1999 and December 2003, as well as patients' demographic information. We also abstracted the body site of the examination, namely cranium, face and neck, trunk (including pelvis, spine, chest and abdomen), and extremities, when available (43% of study examinations), from the database. Since the reason for referral for CT is not documented in the MHS central database, we analyzed all diagnoses (excluding infectious and mental diseases) in patients' medical files within 21 days following the examination. Diagnoses were categorized into large groups according to the 9th revision of the International Classification of Diseases [9].

The data collected for this study were analyzed using descriptive statistical procedures for calculating frequencies and percentages, along with cross-tabulation chi-squared tests for categorical variables (site of CT examination and gender). Differences in age between patients with 10 or more examinations and others were evaluated using the Mann-Whitney test. A Kruskal-Wallis test was performed for annual comparisons of patients' age at examination and for different medical settings where examinations were performed (community, MHS contracted hospitals, and tertiary medical centers). Proportions of cranial scans by sex were compared using the chi-squared test. The analyses were conducted using SPSS 12.0 (SPSS, Chicago, Ill.). The study was approved by the MHS internal review board.

Results

During the observation period (2.7 million person-years of follow-up), 22,233 examinations were documented in 18,075 patients (1.2 per person or 8.4 per 1,000 person-years).

The mean and median ages at examination were 11.1 years (SD 5.5 years) and 12.0 years, respectively. The age distribution in the MHS and in the United Kingdom [4] is depicted in Fig. 2. Infants in their first year of life comprised 5% of pediatric patients undergoing CT scans in MHS, but less than 1% in the UK. Between 4 and 10 years of age the frequency of CT was similar in the two countries, but at age 11 years the proportion of patients undergoing CT scans in the UK became slightly higher than in MHS. Approximately 12% of all pediatric CT scans in the UK were performed on 18-year-old patients compared with only 8% in our population. In MHS, most examinations (87%) were conducted in five tertiary centers and five large imaging centers countrywide. Boys comprised a higher proportion of all patients undergoing scans, ranging from 54% and 56% among children aged 10–14 years and 5–9 years, respectively, to 58% and 59% among those aged <5 years and 15–18 years, respectively. We observed a significant (P<0.01) difference in the age

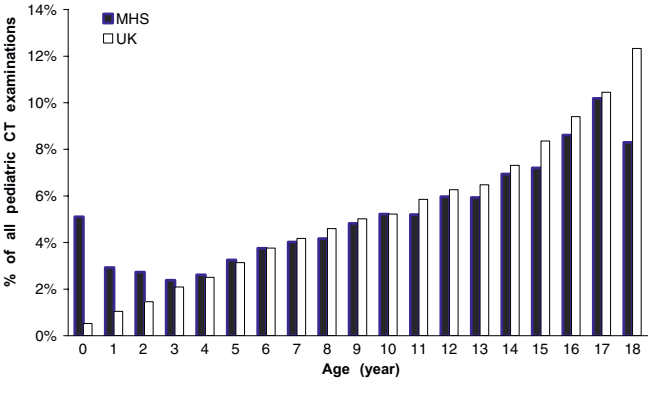


Fig. 2 Age distribution of pediatric patients undergoing CT examinations in a large Israeli HMO and previously reported data from the United Kingdom (Israeli data from Maccabi Healthcare Services, 1999–2003; UK data from reference [4])

distribution of the study patients by the type of facility performing the CT examination. Patients having CT examinations in tertiary medical centers (n=5,423) were younger (mean age 9.4 years; SD 6.0 years) than those (n=4,258) examined in MHS contract hospitals (10.4±5.5 years) who, in turn, were younger than patients (n=12,521) examined in the community setting (12.3±4.9 years).

The age-specific rates of CT examinations in MHS are shown by calendar year in Fig. 3. Children age 3 years had the lowest rate of CT examinations. At age 4 years, the rate increased sharply with increasing age in all calendar years. The number of CT scans performed reached a maximum of 5,346 (10.1 per 1,000) in 2001 compared to 3,562 (7.0 per 1,000) in 1999 and 3,499 (6.3 per 1,000) in 2003. For most ages, a monotonic increase in examination rates was recorded from 1999, the year of the earliest data available, through 2002. A change in this trend was found in 2003, when the lowest rates were observed. Examinations performed under sedation (n=1,724) were nearly all (97%) done among children less than 8 years of age (Table 1). Sedation was used in 42% of the scans among children aged <5 years but only in 13% and 0.6% of the scans among those aged 5–8 years and 9–18 years, respectively. The proportion of children (<10 years) who were sedated rose from 18% over the period 1999 to 2001 to 25% and 30% in 2002 and 2003, respectively.

Similar to previous reports [10, 11], imaging of the cranium was very common, ranging from 78% of CT examinations in young children (<5 years) to 39% in adolescents aged 16–18 years (Fig. 4). In contrast, at young ages only 3% of CT scans were of the face or neck compared with 16% in adolescents. Scans of the trunk comprised 23% of all CT examinations. No distinct differences were obtained in site distribution between infants (<1 year) and toddlers (1–4 years). Among girls aged 15 years and older, 49% of all CT examinations were of the cranium compared to 38% among boys (P<0.001). Differences were not found among younger patients.

In 63% of all examinations, at least one diagnosis was recorded within 21 days following the examination and two or more diagnoses were documented in 28%. The two most frequent (22%) diagnostic groups were diseases of the respiratory system and signs of ill-defined conditions (e.g. headaches), as shown in Table 2. For diseases of the nervous system, the proportion decreased gradually with increasing age, from 22% among young children to 11% among adolescents, whereas a reverse trend was observed for diseases of the musculoskeletal system and connective tissues. Injury was documented in 13% of the records in young children and 9–10% in older ones. Congenital anomalies and conditions originating in the prenatal period were the reason for performing a CT scan in a larger proportion (10%) of young children (of whom 64% were infants in their first year of life) than older groups. Neoplasms were recorded in 2–4% of all scans across age groups.

A significant fraction (15%) of patients having CT scans had a prior examination within the 5-year period of study; 12% had two examinations, less than 1% had more than 10 examinations and one patient was examined 28 times. Of the 10 children with 15 or more CT examinations, six were oncology patients, three had upper respiratory tract infections and one was diagnosed with Gaucher disease. Of all examinations, 16% were conducted on children

Table 1 Proportion of pediatric CT scans that used sedation by age

Age (years)	Total scanned	Sedation (%)
<1	1,218	483 (39.7)
2	674	304 (45.1)
3	586	287(49.0)
4	511	176 (34.4)
5	577	149 (25.8)
6	707	123 (17.4)
7	810	74 (9.1)
8	875	36 (4.1)
9	956	25 (2.6)
10–18	15,319	67 (0.4)
Total	22,223	1,724 (7.8)

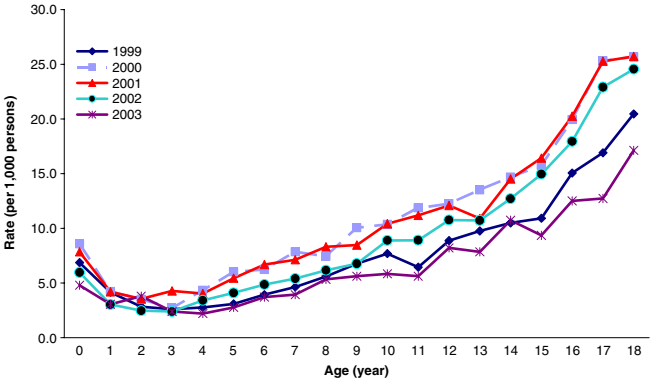
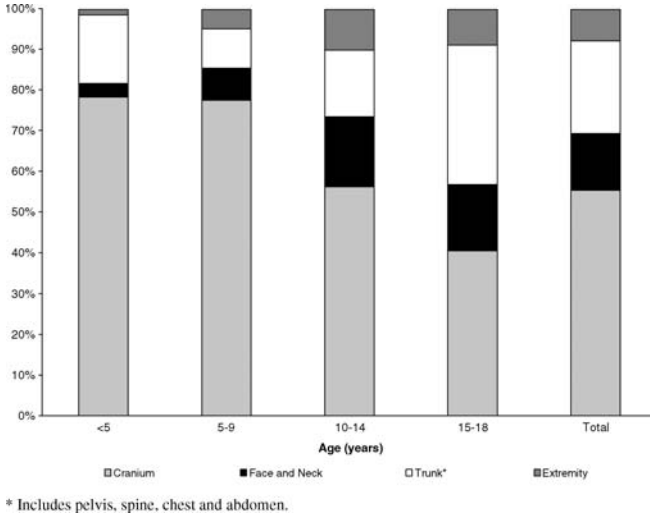


Fig. 3 Age-specific rates of CT examination among pediatric patients in a large Israeli HMO, according to year of examination (1999–2003)



* Includes pelvis, spine, chest and abdomen.

Fig. 4 Distribution of CT examinations by body site and patient age at examination (*Trunk* includes pelvis, spine, chest and abdomen)

Table 2 Proportion (%) of diagnoses within 21 days following CT examination, according to age at examination

ICD-9 category	Age at examination (years)				
	<5 (*n*=3,701)	5–9 (*n*=4,433)	10–14 (*n*=6,542)	15–18 (*n*=7,557)	All (*n*=22,223)
Diseases of respiratory system	28.7	20.0	22.9	19.7	22.2
Symptoms, signs and ill-defined conditions (headache, dizziness, etc.)	24.9	21.5	21.2	20.6	21.7
Diseases of nervous system and sense organs	22.1	16.2	12.4	11.3	14.4
Diseases of musculoskeletal system and connective tissue	4.4	5.5	12.7	20.6	12.6
Injury and poisoning	12.8	8.5	9.9	9.7	10.1
Diseases of genitourinary system	6.8	4.6	4.2	5.4	5.1
Diseases of digestive system	6.8	4.4	4.3	5.3	5.1
Diseases of skin and subcutaneous tissue	5.2	2.7	3.9	5.9	4.6
Congenital anomalies	10.0	2.2	2.3	1.7	3.4
Neoplasms	2.9	2.3	3.4	4.0	3.3
Endocrine, nutritional, and metabolic diseases, and immunity disorder	5.1	2.9	3.3	2.6	3.3
Disease of blood and blood-forming organs	1.6	0.6	0.8	0.9	0.9
Diseases of circulatory system	1.4	0.3	0.5	1.1	0.8
Complications of pregnancy, childbirth, and the puerperium	0.3	0.2	0.4	0.7	0.4
Certain conditions originating in prenatal period	0.8	0.0	0.1	0.1	0.2
None of the above	34.4	40.4	37.6	34.5	36.5

<5 years of age, and this age group had repeated CT on the same day significantly ($P<0.001$) more frequently (19%) than older children (2%).

Discussion

According to the NHAI, the State is responsible for providing health services to all citizens through four national HMOs. Every HMO, including MHS, is obligated to insure every resident who wishes to join it, irrespective of age, gender, physical condition, medical history or any other criterion. Therefore, the MHS membership includes people from the full spectrum of Israeli society. The present study includes data from examinations performed in hospitals and community clinics among the 560,000 MHS members aged 18 years or less (2003), 24% of the Israel population of this age. Since prescribed CT examinations are free of charge to all citizens in Israel, the MHS data should be broadly representative of the national CT patterns and use. The similarity in age distribution to previously published data from the UK [4], and the similarity in the proportion of children aged <5 years in our study (18%) and that reported in the US (17%) [12] support the external validity of the current study. However, 18-year-old patients comprised a substantially lower proportion in our data compared to the UK data, which is probably explained by the fact that at this age, most MHS members are drafted into mandatory military service and cease to receive medical care at the HMO. In accordance with findings from countries with similar levels of health-care services, males comprise a higher proportion of the total examined population [8]. A possible explanation for this difference is a higher trauma rate among boys, as was recently reported by the Israel trauma registry [13]. According to these data, boys comprised 59% of all children <4 years old injured at home between 1997 and 2001. Rates reached equality at about the age of 20 years [13].

Extrapolating the MHS age- and gender-specific annual examination rate to the entire ≤18-year-old population in Israel (2.2 million people), the estimated annual number of CT examinations in Israel would be 17,686. This number comprises only 3% of the annual number of CT scans in the country in 1999 (540,273) [14]. This rate is significantly lower than the average of 6% in other countries with similar health-care levels [8]. However, since overall CT utilization in Israel is higher compared to those countries, the actual age-specific CT rates for this age group are probably comparable.

CT is a standard, modality not only to diagnose, but also to follow the course of disease. It is, therefore, not surprising that a substantial proportion of the study population had more than a single CT examination within the study period. The data also suggest that almost one-fifth of children aged <5 years undergoing a CT examination had a second scan on the same day. Similarly, a study of 32 infants undergoing a helical CT scan of the chest or abdomen found that 10 of them (31%) had multiphase examinations [15]. Some of these multiple exposures may be reduced when medically appropriate [16] since there are few indications for multiple scans.

Sedation was indicated in 31% of all children under 8 years of age, similar to the rate (40%) calculated for 264 children of the same age group who had conventional CT in a pediatric hospital [17]. Considerably lower sedation rates

(3–20%) have been reported for children of similar age who underwent helical CT [11, 17, 18]. The growing number of helical CT scans for pediatric use would thus be expected to reduce the need for sedation among our pediatric patients and consequently, the risk of complications and disruption of the patient's normal daily activities. However, our data show that the rate of sedation during recent years has not declined, but actually almost doubled in the study period from 17.7% in 1999 to 30.2% in 2003. Further study is warranted to examine this unpredicted increase.

Absorbed doses from CT examinations are among the highest in diagnostic radiology. Because doses are directly related to the quantity of radiation exposure, minimizing CT examinations will reduce patient dose. Exposure of children requires special caution in view of their increased radiation-related tumor risk. Previous assessments have shown that although children absorb less radiation than adults, their organs are so small that the resultant doses (energy absorbed divided by organ mass) may be higher [19], especially among infants (<1 year) [20]. Huda et al. [21] have also reported large variability in the computed radiation dose parameters indicating that it should be possible to reduce infant doses from routine head CT examinations, without any adverse effect on diagnostic imaging performance. For routine head CT scans, the average dose reduction for infants weighing between 4 and 8 kg would be expected to range between 40% and 60%.

A survey of pediatric radiologists indicates that size-based adjustments for CT in children are not always made [22]. From discussions held in 2004 at the National Council for Pediatric and Child Health in the Israel Ministry of Health, it was reported that many CT technicians do not decrease the dose as appropriate for unplanned pediatric CT scans, as this time-consuming procedure may cause a longer waiting time for other patients (National Council for Pediatric and Child Health meetings stenographs, 2004). One more likely reason for this lack of adjustment is that because CT is a digital technology, image quality may improve at higher radiation doses, but unlike radiography in which high doses may result in overexposure, or dark radiographs, there is no potential reduction in image quality when doses are too high [12].

While CT remains a crucial tool for pediatric diagnosis, physicians, radiology technologists and health authorities need to work together to reduce the radiation dose to children to as low as reasonably achievable (ALARA). The following steps are important in reducing exposure and dose: performing only necessary CT examinations and considering substituting other modalities (e.g. US or MRI) that do not involve ionizing radiation; adjusting CT exposure parameters based on patient size, and organ or region scanned while maintaining adequate scan resolution; and increasing quality assurance to avoid unnecessary repeated scans. Long-term strategies may also include the development and use of pediatric CT protocols and the dissemination of information through public and professional organizations. In addition, education of radiologists, technicians, and other health-care providers about the relationship between CT parameters, image quality, and radiation dose to cancer risk is needed [23]. This is of particular importance as a recent survey in a tertiary center in the USA found that 61% of 39 radiologists estimated the dose from diagnostic CT to be approximately equal to or smaller than the dose from one chest radiograph, while it actually is 100- to 250-fold higher [24]. In the same survey, researchers found that most of the patients and emergency department physicians and more than half of the radiologists did not perceive a possible increased cancer risk associated with diagnostic CT [24].

In 2003, MHS authorities realized it was important to triage CT examinations to eliminate inappropriate examinations and to utilize procedures providing equal information with less or no ionizing radiation. At that time, they initiated a new policy to reduce misuse and overuse in imaging procedures, including CT examinations. According to the new policy, every primary care physician is obligated to consult, through a computerized telemedicine technology, a radiology center before referring patients for CT. The center's radiologists consider the appropriateness of every referral according to accepted practice protocols. Advanced telecommunication technology allows a prompt reply without any considerable delays in service. By this policy, physicians are often advised to refer the patient to conventional radiography, US or MRI, which can be as effective as CT, but have lower radiation exposure [25]. The introduction of this policy may well explain the reduction in CT use in 2003.

Utilization data such as these should be routinely updated to allow monitoring of trends in the use of CT among pediatric patients in Israel. Further research is needed to determine the relationship between the quality of CT scans and the dose per scan and to investigate whether CT scanning doses are adjusted properly downward for young and small children. Collecting data on CT use may also provide a way to identify a large cohort for future follow-up studies to clarify the relationship between radiation exposure from CT scans and subsequent cancer risk. Such studies have been recognized as a special research need by the Committee to Assess Health Risks from Exposure to Low Levels of Radiation in the recently released BEIR VII report [26].

Acknowledgement This research was supported in part by the Intramural Research Program of the Radiation Epidemiology Branch, National Cancer Institute, NIH.

References

1. Shrimpton PC, Edyvean S (1998) CT scanner dosimetry. Br J Radiol 71:1–3
2. Hart D, Wall BF (2004) UK population dose from medical X-ray examinations. Eur J Radiol 50:285–291
3. Brenner DJ (2002) Estimating cancer risks from pediatric CT: going from the qualitative to the quantitative discussion. Pediatr Radiol 32:228–231

4. Brenner D, Elliston C, Hall E, et al (2001) Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR 176:289–296
5. Linton OW, Mettler FA Jr; National Council on Radiation Protection and Measurements (2003) National conference on dose reduction in CT, with an emphasis on pediatric patients. AJR 181:321–329
6. Ron E (2003) Cancer risks from medical radiation. Health Phys 85:47–59
7. Brasch RC, Boyd DP, Gooding CA (1978) Computed tomographic scanning in children: comparison of radiation dose and resolving power of commercial CT scanners. AJR 131:95–101
8. UNSCEAR (2000) Sources and effects of ionising radiation. Annex D: medical radiation exposures. United Nations Scientific Committee on the Effects of Atomic Radiation, New York
9. World Health Organisation (1975) International classification of diseases (ICD), 9th revision. WHO, Geneva
10. Mettler F, Wiest P, Locken J, et al (2000) CT scanning: patterns of use and dose. J Radiol Prot 20:353–359
11. Sacchetti A, Carraccio C, Giardino A, et al (2005) Sedation for pediatric CT scanning: is radiology becoming a drug-free zone? Pediatr Emerg Care 21:295–297
12. Frush D, Donnelly L, Rosen N (2003) Computed tomography and radiation risks: what pediatric health care providers should know. Pediatrics 112:951–957
13. Sikron F, Giveon A, Aharonson-Daniel L, et al (2004) My home is my castle! Or is it? Hospitalizations following home injury in Israel, 1997–2001. Isr Med Assoc J 6:332–335
14. Luxenburg O, Vaknin S, Pollack G, et al (2003) Utilization patterns of CT and MRI in Israel. Harefuah 142:810–814
15. Paterson A, Frush DP, Donnelly LF (2001) Helical CT of the body: are settings adjusted for pediatric patients? AJR 176:297–301
16. Donnelly LF, Emery KH, Brody AS, et al (2001) Minimizing radiation dose for pediatric body applications of single-detector helical CT: strategies at a large children's hospital. AJR 176:303–306
17. Kaste SC, Young CW, Holmes TP, et al (1997) Effect of helical CT on the frequency of sedation in pediatric patients. AJR 168:1001–1003
18. Pappas JN, Donnelly LF, Frush DP (2000) Reduced frequency of sedation of young children with multisection helical CT. Radiology 215:897–899
19. Huda W (2002) Dose and image quality in CT. Pediatr Radiol 32:709–713
20. Shrimpton PC, Hillier MC, Lewis MA, et al (2005) Doses from computed tomography (CT) examinations in the UK – 2003 review. Health Protection Agency, Didcot, UK. Available at http://www.hpa.org.uk/radiation/publications/w_series_reports/2005/nrpb_w67.htm. Cited 6 Dec 2005
21. Huda W, Atherton JV, Ware DE, et al (1997) An approach for the estimation of effective radiation dose at CT in pediatric patients. Radiology 203:417–422
22. Hollingsworth C, Frush DP, Cross M, et al (2003) Helical CT of the body: a survey of techniques used for pediatric patients. AJR 180:401–406
23. Frush DP (2002) Pediatric CT: practical approach to diminish the radiation dose. Pediatr Radiol 32:714–717
24. Lee CI, Haims AH, Monico EP, et al (2004) Diagnostic CT scans: assessment of patient, physician, and radiologist awareness of radiation dose and possible risks. Radiology 231:393–398
25. National Cancer Institute (2002) Radiation and pediatric computed tomography: a guide for health care providers. National Cancer Institute, Bethesda, MD
26. National Academies of Sciences (2005) Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2. http://www.nap.edu/books/030909156X/html